

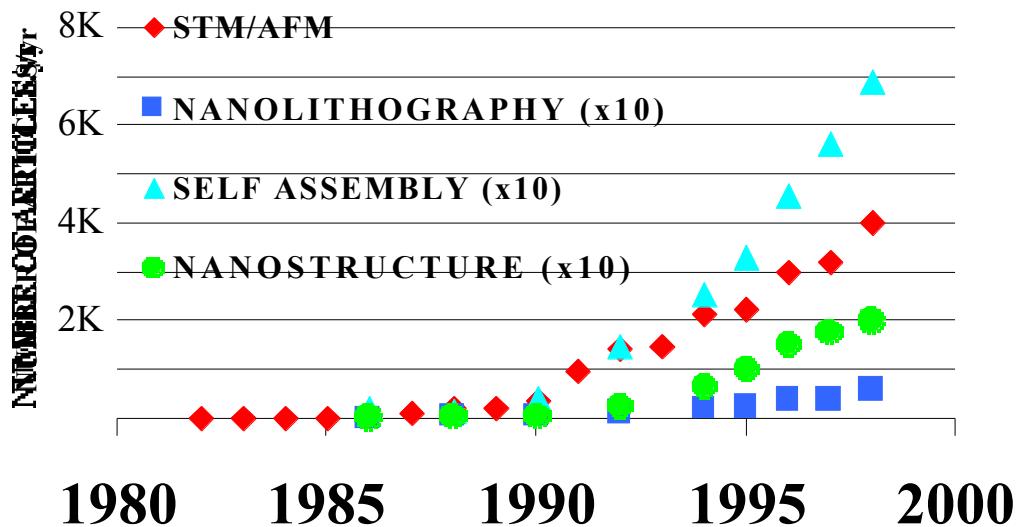
# **National Nanotechnology Initiative**

## **Toward a Revolution in Materials**

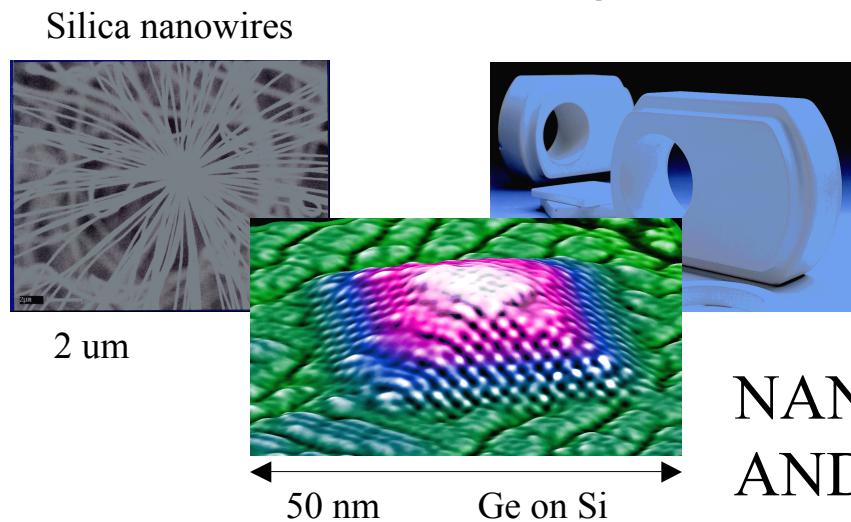
Dr. James S. Murday  
Head, Chemistry Division, Naval Research Laboratory  
Executive Secretary, Nanometer Science, Engineering and Technology Subcommittee  
National Science and Technology Council

4<sup>th</sup> Industrial Energy Efficiency Symposium and Exposition  
DOE Office of Industrial Technology  
February 2001

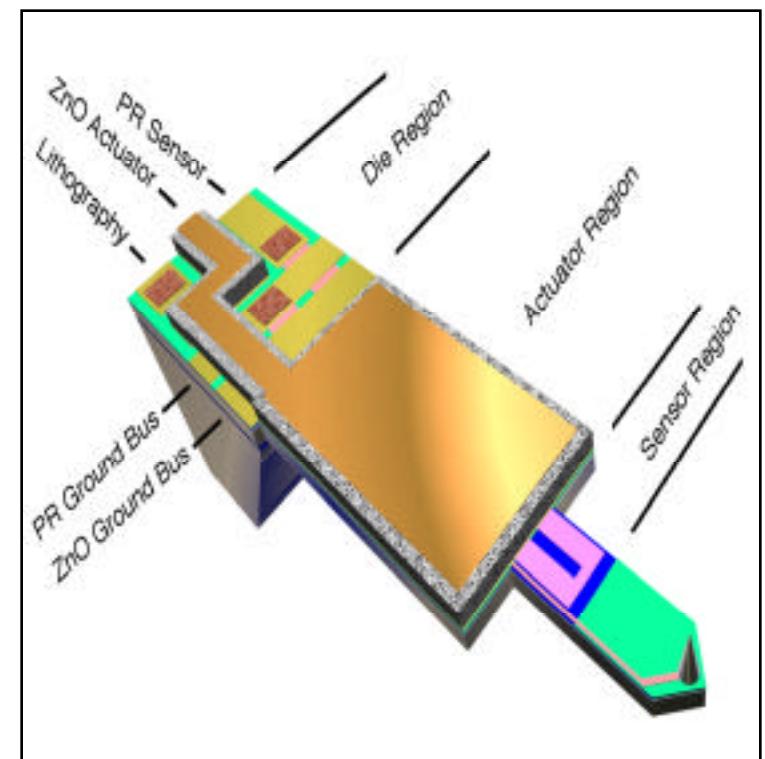
# NANOSCIENCE/NANOTECHNOLOGY REVOLUTION



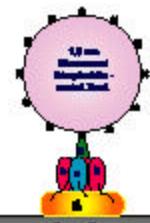
PROXIMAL PROBES  
PROLIFERATING



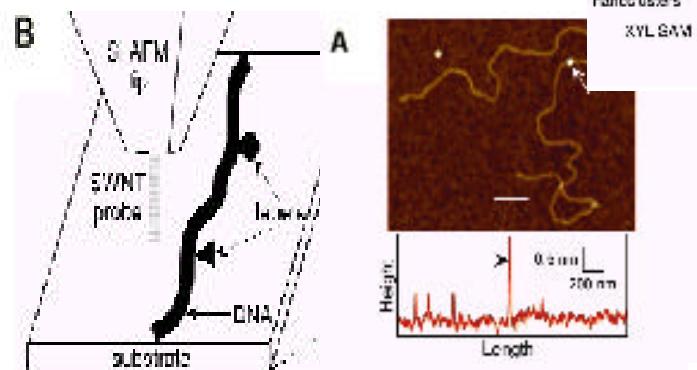
OPPORTUNITIES  
EXPLODING



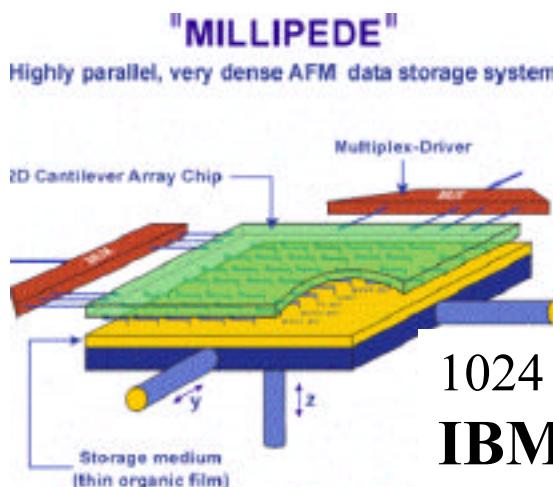
NANOSTRUCTURE FORMATION  
AND ASSEMBLY DIVERSIFYING



## Biomolecular Motor Nanotechnology 1999



## CNT Chemical Image of DNA Nature 2000

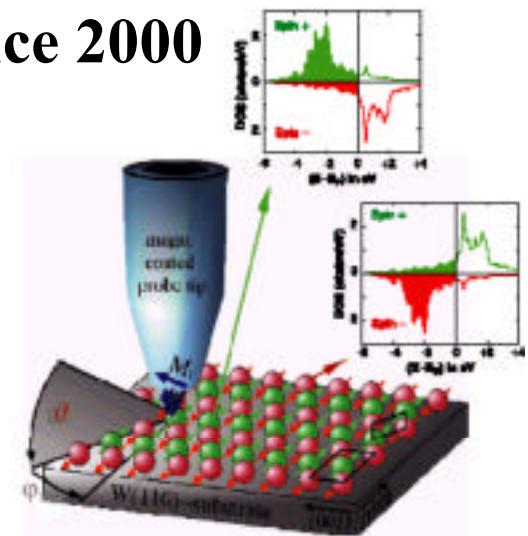


1024 Parallel SPMs  
IBM Zurich 2000

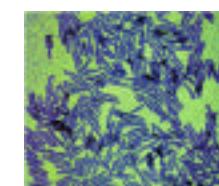
## Atomic Magnetic Imaging of an Antiferromagnet Science 2000

Nanocluster  
Guided  
Self Assembly

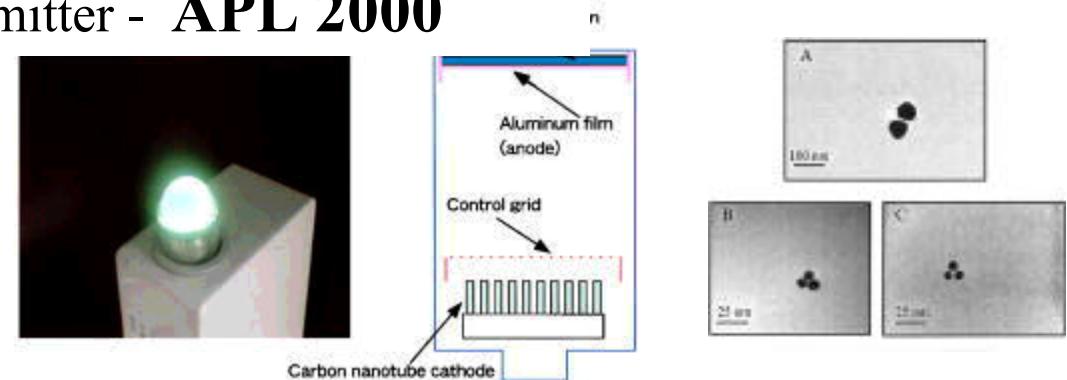
APL 2000



Nanocrystals for solar cell efficiency  
APL 2000



Carbon Nanotube Field Emitter - APL 2000

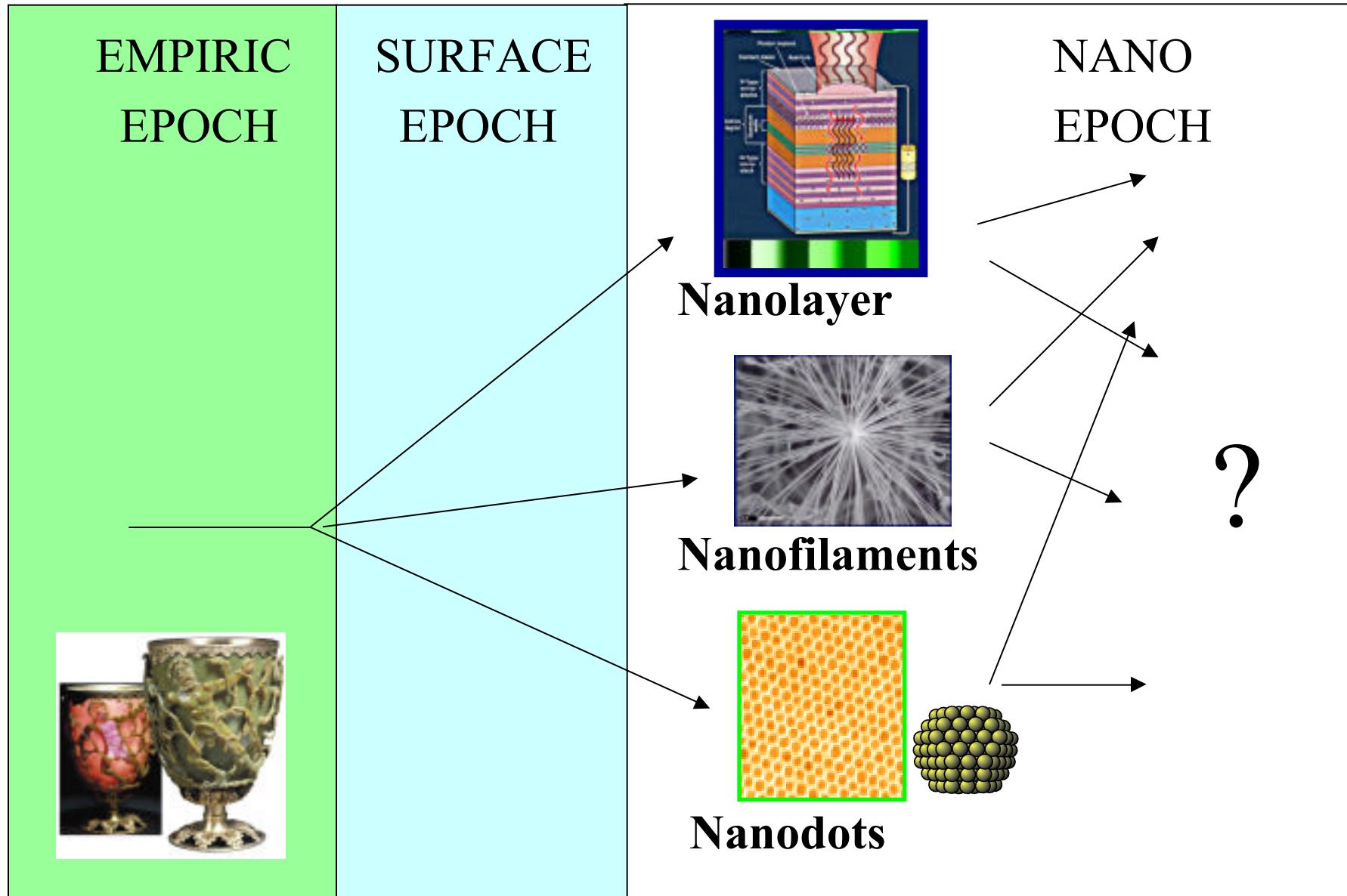


3D Chemical Linked Nanoclusters  
JACS 2000

SCIENCE AND TECHNOLOGY OF NANOMETER STRUCTURES  
CHARACTERISTIC LENGTHS IN SOLID STATE SCIENCE MODELS

FIELD	PROPERTY	SCALE LENGTH
ELECTRONIC	ELECTRON WAVELENGTH	10-100nm
	INELASTIC MEAN FREE PATH	1-100m
	TUNNELING	10m
MAGNETIC	DOMAIN WALL	10-100m
	EXCHANGE ENERGY	0.1nm
	SPIN-FLIP SCATTERING LENGTH	1-100 nm
OPTIC	QUANTUM WELL	1-100nm
	EVANESCENT WAVE DECAY LENGTH	10-100nm
	METALLIC SKIN DEPTHS	10-100nm
SUPERCONDUCTIVITY	COOPER PAIR COHERENCE LENGTH	0.1-100 nm
	MEISSNER PENETRATION DEPTH	1-100nm
MECHANICS	DISLOCATION INTERACTION	1-100nm
	GRAIN BOUNDARIES	10m
NUCLEATION/GROWTH	DEFECT	0.1-10nm
	SURFACE CORRUGATION	10m
CATALYSIS	LOCALIZED BONDING ORBITALS	0.01-0.1nm
	SURFACE TOPOLOGY	1nm
SUPRAMOLECULES	PRIMARY STRUCTURE	0.1nm
	SECONDARY STRUCTURE	1nm
	TERTIARY STRUCTURE	10-100nm

# Paleontology of Nanostructures



1960

1990

# IWGN (NSET)

## PROGRAM RECOMMENDATIONS

	FY00	FY01	FY02
“FUNDAMENTAL” RESEARCH			
GRAND CHALLENGES	\$87M	\$140M	
	\$71M	\$125M	
NANOSTRUCTURED MATERIALS BY DESIGN,	NSF		
NANOELEC, OPTOELEC, MAGNETICS,	DOD		
ADVANCED HEALTHCARE/THERAPEUTICS,	NIH		
ENVIRONMENTAL IMPROVEMENT,	EPA		
ENERGY CONVERSION/STORAGE,	DOE		
TRANSPORTATION,	DOT		
MICROCRAFT ROBOTICS,	NASA		
BIONANOSENSORS FOR BIOTHREAT,	NIH, DOD		
INTRUMENTATION & METROLOGY,	NIST		NEW
MANUFACTURING SCIENCE			NEW
CENTERS/NETWORKS	\$47M	\$66M	
INFRASTRUCTURE	\$50M	\$77M	
ETHICAL/SOCIAL IMPLICATIONS	\$15M	\$21M	
TOTALS	\$270M	\$422M	

# NATIONAL NANOTECHNOLOGY INITIATIVE

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<u>AGENCY</u>	<u>PROGRAM EMPHASIS</u>
DOC	Measurements and standards
DOD	Nano-electronics, - materials, -bioltechnology
DOE	Energy science, environment, non-proliferation
DOJ	Forensic sensing, ballistic protection
DOT	Smart, light weight, affordable materials, sensing
DOTreas	Taggants, low wear materials
EPA	Chemical sensing, environmental protection
NASA	Lighter, smaller spacecraft; rad-hard electronics
NIH	Therapeutics, diagnostics, biomaterials
NSF	Science/engineering fundamental knowledge
USDA	Agricultural yield

# **Commercial Impact**

## **(Potential \$T Markets)**

Nanomaterials

Information Technology Materials

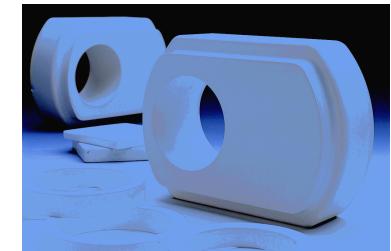
Nanobiotechnology

# NANOMATERIALS



Q-Dot Contrast Enhancers; Frankel, MIT

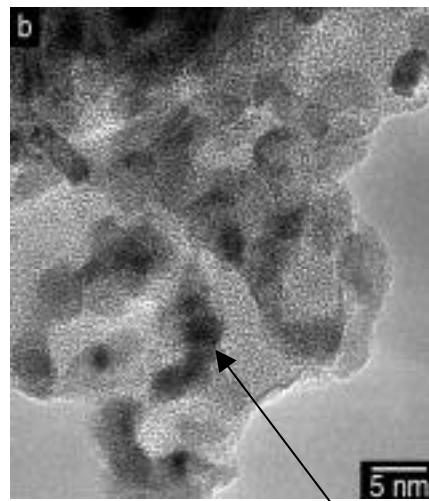
## NANOSTRUCTURES



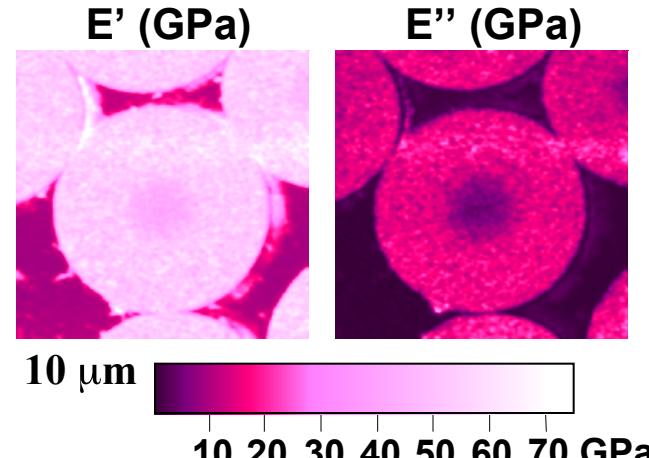
Netshape Formed Nanoceramics; Siegel, RI

## CONSOLIDATED NANOSTRUCTURED MATERIALS

### NANOCOMPOSITES

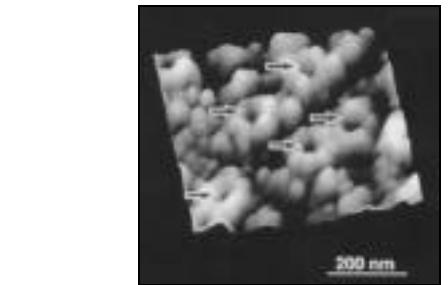


Nanocrystalline  $\text{RuO}_2$  wire in Silica Aerogel; Rolison, NRL

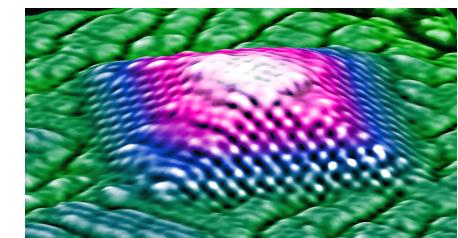


Composite Moduli Measurement; Wahl, NRL

### NANOPOROUS MATERIALS



Cell Membrane; Oberleithner, Münster



### DIRECTED SELF ASSEMBLY

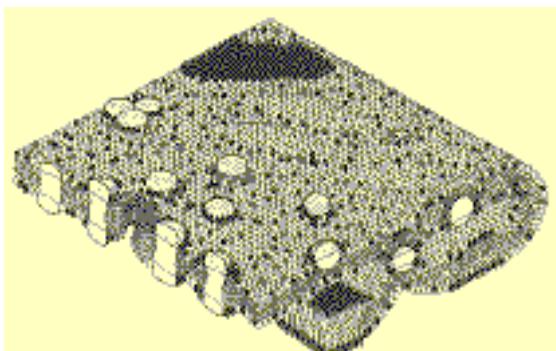
# NanoMaterials

## General Characteristics

- Multiple Phases (2+ constituents)**
- Nanoscopic dimensions (1-100 nm)**
- Phase Size / Separation ~ 1**
- Controllable morphology**

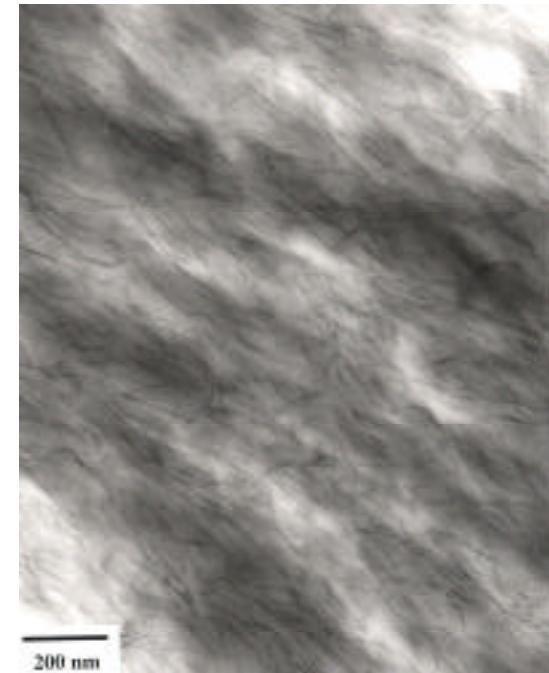
## Structural Implications

- Ultra-large interfacial area per volume**
- High fraction interfacial (interphase) material**
- Stabilization of non-equilibrium phases**
- Short distances between components**
- Confinement**



## Consequences

- Size-dependent physics**
- Size-dependent chemistries**
- Compartmentalization**
- Multifunctionality**

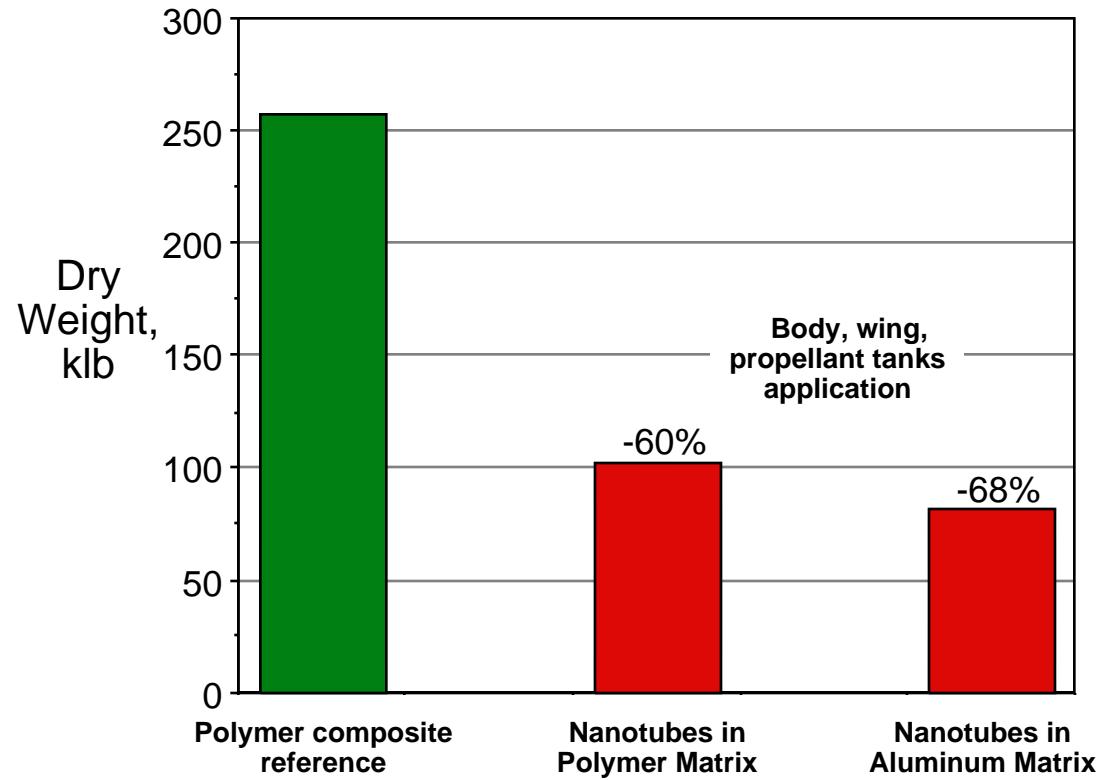


## Polymer Nanocomposite

Fine dark lines: edge view of silicate layers  
Matrix: Nylon 6  
50,000 (0.001  $\mu\text{m}$ ) times smaller  
than the thickness of human hair (50  $\mu\text{m}$ )

# Nanotechnology: SSTO Systems Analysis Results

Results for Nanotube-Reinforced Polymer (CNTFRP) and Nanotube-Reinforced Aluminum (CNT/Al) Composites compared to an advanced carbon fiber reinforced polymer (IM7 CFRP) composite



**Results: Total gross weight is reduced by over 50% relative to the best available composite material under development.**

Hirschbein, NASA

# Nanophase (NP) Aluminum Alloy Technology

**Objective:** Develop high-strength, lightweight bulk nanophase Al alloys as a replacement for conventional aerospace alloys (e.g., Ti)

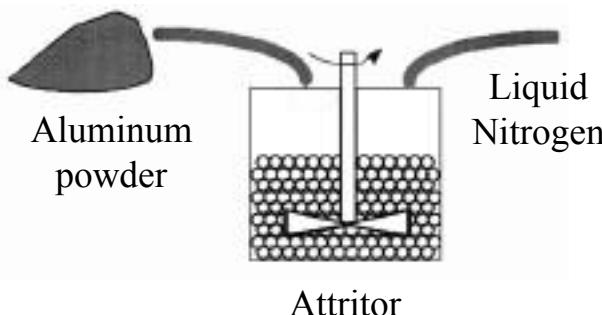
**Success:** Demonstrated production scale-up of cryomill-synthesis and warm-work process

**Application:** LH<sub>2</sub> rocket engine fuel pump  
(Integrated Powerhead Demonstrator)

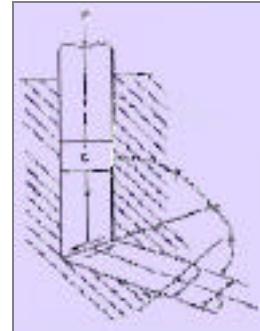


## Processing Methods

### Cryomill-synthesis



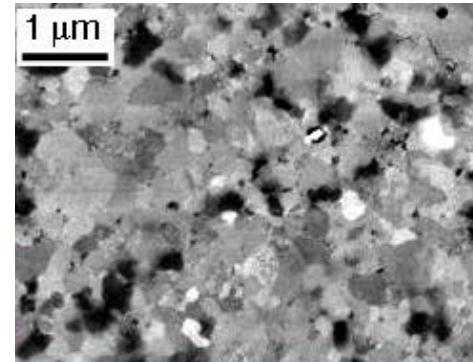
### Warm-working



Equal Channel  
Angular Extrusion

## Mechanical Properties (20°C)

	$\sigma_y$ (MPa)	(%)	RA(%)
NP Al - 1 <sup>st</sup> Gen.	<b>550</b>	<b>10</b>	<b>20</b>
NP Al - 2 <sup>nd</sup> Gen.	<b>830</b>	<b>5</b>	<b>10</b>
7075-T6	505	11	10



Nanophase Al Microstructure



115 mm Dia.  
Nanophase Al Extrusion

Lee Semiatin, 937-255-1345, lee.semiatin@afrl.af.mil  
Mike Uchic, 937-255-4784 michael.uchic@afrl.af.mil

# NANOMETER SCIENCE AND TECHNOLOGY

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## EVOLVING SUCCESS STORY: NANOSTRUCTURED COATINGS

1996: First nanostructured coating (WC-Co) produced by thermal spray processing

1997: Nanostructured ceramic coatings successfully fabricated using plasma spray

1998: Nanostructured ceramic coatings produced directly from liquid precursors, greatly lowering cost

1999: Begin full scale testing of nanostructured coatings on shipboard components.

*Nanostructured thermal sprayed coatings offer greatly enhanced adhesion, toughness, wear resistance and machinability and thickness (compared to conventional coatings)*

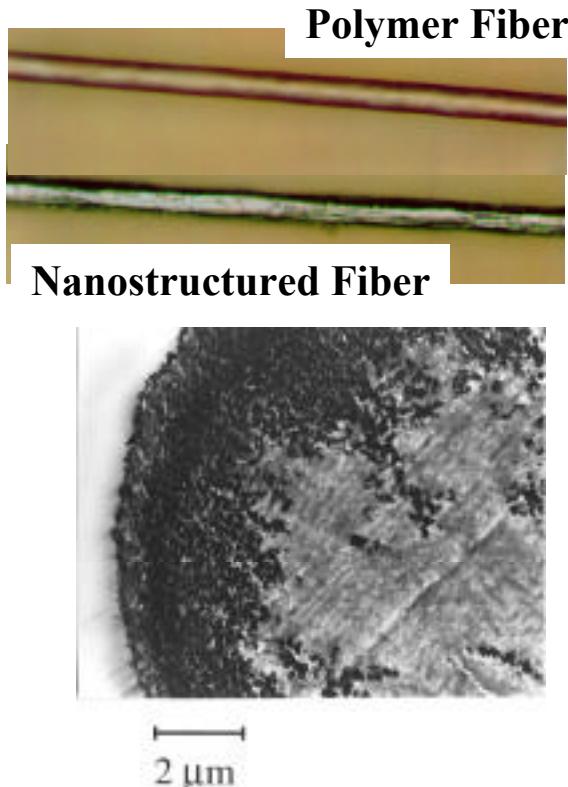


Kabacoff, ONR

# High Performance, Nanostructured Conducting Fibers Technology

**Objective:** Controlled deposition of nanoparticle using transient mesostructure of polymer existing during processing as template

**Success:** Multifunctional materials:  
maintain processing and strength of polymer fiber  
adding conductivity of metal

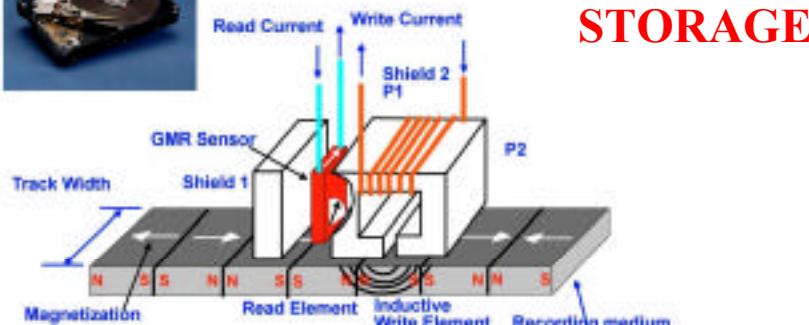


	Modulus (GPa)	Strength (MPa)	Strain (%)	Conductivity (S/cm)
Polymer Fiber	95.2	900	1.98	$10^{-12}$ - $10^{-14}$
Nanostructured Fiber	51.8	1050	3.29	$2.5 \times 10^4$
Metal Fiber (Ag)	76	55	60	$6.3 \times 10^5$

**50% lighter and 200x stronger than current signal lines**

Rich Vaia, 937-255-9184, richard.vaia@afrl.af.mil

# INFORMATION TECHNOLOGY MATERIALS



Magnetic recording process.

GMR Reading Head; IBM

## STORAGE

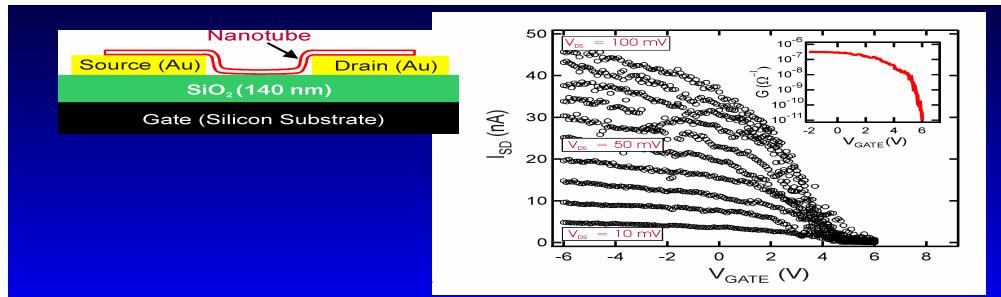
## DISPLAY



CNT FED Display; Zhou, UNC

## LOGIC

## TRANSMISSION



CNT FET; Avouris, IBM

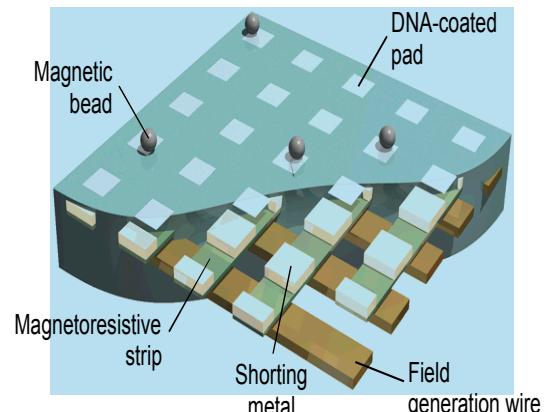
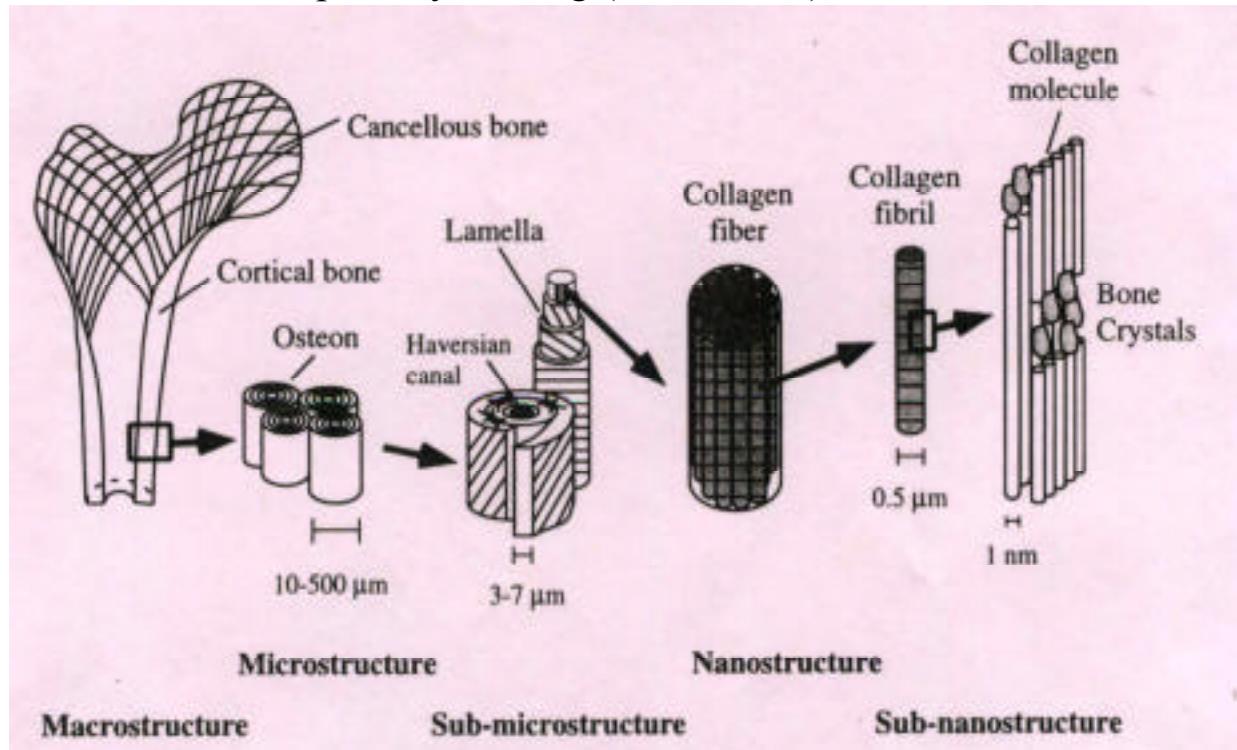


Superlattice VCSEL; Honeywell

# NANOBIOTECHNOLOGY

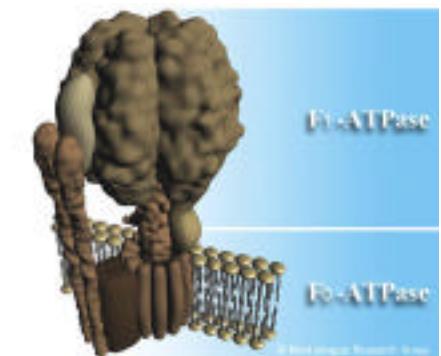
## Earlier Detection and Treatment of Disease

Contrast Agents for Imaging  
Sensors  
Susceptibility Testing (DNA/RNA)



BARC Sensor; Colton, NRL

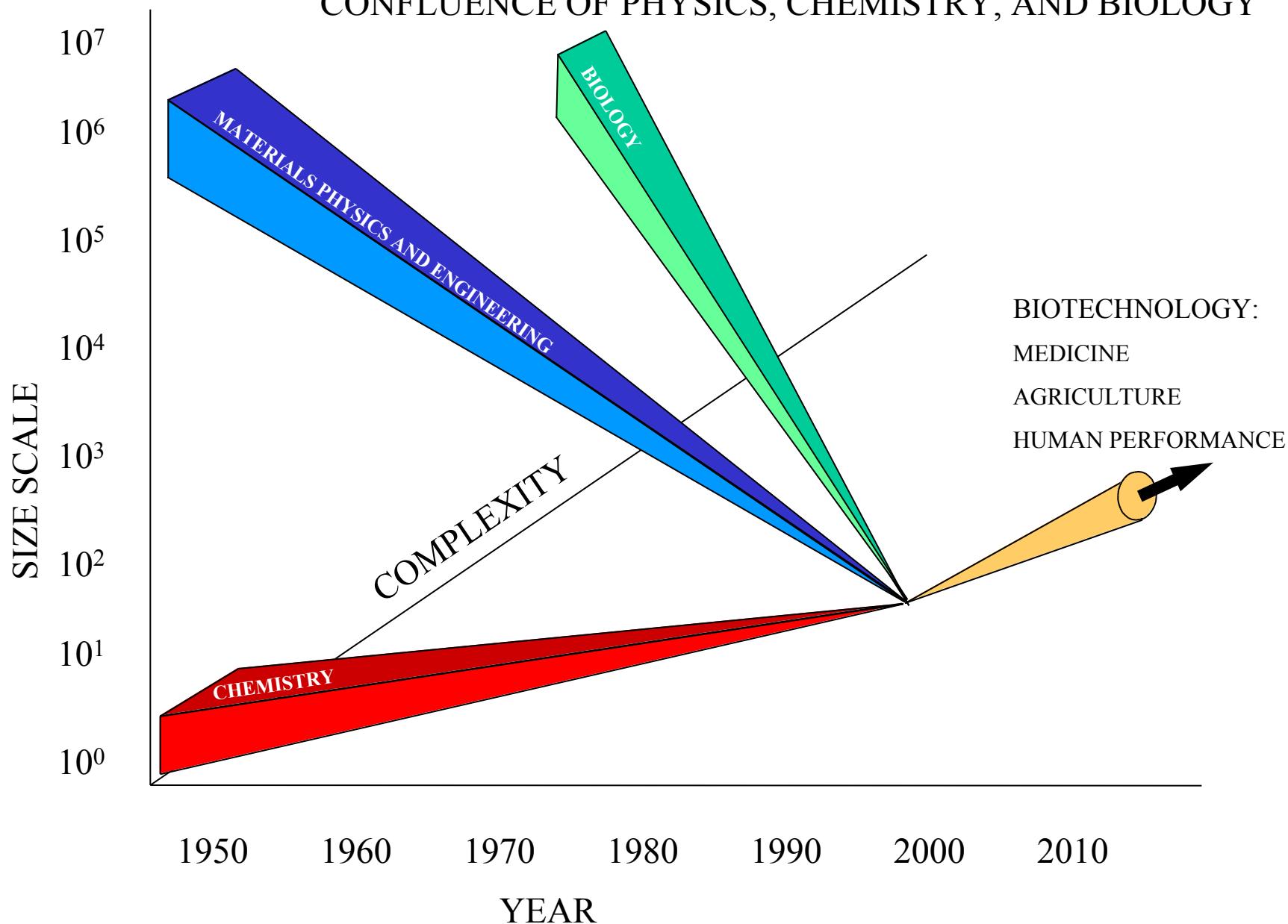
## Improved Implants



Molecular Motor; Montemagno, Cornell

**Therapeutic Delivery**  
Enhanced Solubility  
Targeted, Local Delivery

# NANOMETER SCIENCE AND TECHNOLOGY: CONFLUENCE OF PHYSICS, CHEMISTRY, AND BIOLOGY



# TECHNOLOGY: FROM METERS TO NANOMETERS IN 60 YEARS

	<b><u>1950 (m)</u></b>	<b><u>1970 (mm)</u></b>	<b><u>1990 (<math>\mu</math>m)</u></b>	<b><u>2010 (nm)</u></b>
Electronic	vacuum tube	transistor	IC chip	quantum corral RTD, SET
Magnetic	magnetic core	disk memory	GMR heads	GMR DRAM
Electromechanical	telephone relay grandfather clock	microswitch quartz crystal	MEMS SAW	NEMS/molecular motor nanoresonator (GHz)
Optic	search light	laser LED	quantum cascade integrated optics	photonic crystal
Medicine	whole blood	cryoprecipitate ( $10^4$ donor/dose)	Chinese hamster ovary/kidney	DNA sequences/repair

*Welcome to the*

## National Nanotechnology Initiative



- [National Nanotechnology Initiative: The Initiative and its Implementation Plan \(PDF 1664kb\) \(HTML\)](#)  
NSTC/NSET Report, July 2000
- Current Solicitations for Proposals:
  - ▶ [National Nanotechnology Initiative Endorsements](#)
  - ▶ [NSTC/NSET Initiatives of Nanoscience and Nanotechnology, NSE](#)
  - ▶ [NSF Partnership](#)
  - [NSF: Nanoscale Science and Engineering \(NSE\)](#)
  - [DOE: Defense University Research Initiatives on NanoTechnology \(DURINT\)](#)
  - [DOE: Nanoscale Science, Engineering, and Technology](#)
  - [EPA: Exploratory Research to Anticipate Future Environmental Issues; Research on Nanotechnology, Natural Sciences, and Socio-economics](#)

**http://www.nano.gov/**